THE USE OF X-RAYS IN INSPECTION METHODS

Paper presented to the Institution, London Section, by G. E. Bell, M.Sc., Ph.D. (of the Physics Department, the National Physical Laboratory, Teddington).

AMONG the various methods which are employed by engineers in the examination of their products the method of X-ray examination is of considerable utility. Properly used and in suitable circumstances, X-rays are capable of demonstrating the majority of defects to which materials are subject while, by the use of gamma rays from radioactive substances, the range of thicknesses and materials which may be examined by radiological methods is greatly increased, steel objects up to 6 in. in thickness having been examined. One advantage of radiological examination over other methods is that it can often detect flaws such as blow holes, cracks, pipes, and oxide inclusions deep within the material, while at the same time the method is non-destructive and does not normally involve any special preparation of the specimen.

For a proper understanding of the potentialities and limitations of radiological examination, it is necessary to consider some of the more important properties of X-rays.

Production of X-rays.

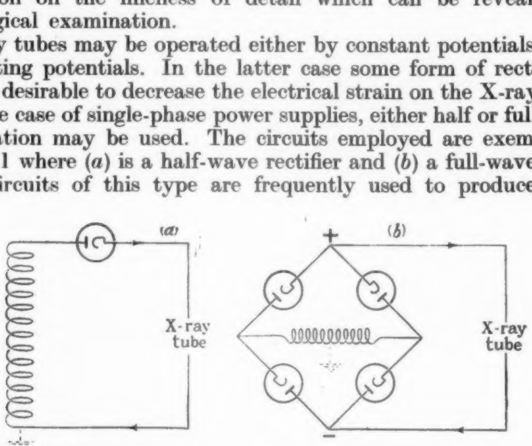
X-rays consist of electromagnetic vibrations, identical with light waves but of much shorter wave-lengths, which are emitted when moving electrons are suitably arrested by atoms, and an X-ray apparatus is essentially designed to produce electrons, impart to them a sufficient velocity and suddenly stop them. In a modern X-ray tube the electrons, which are provided by a hot tungsten filament, are subject to accelerating electric fields up to 200 kV or more supplied by some form of high-tension generator. The elec-trons impinge on a " target " or anode, which usually consists of a block of tungsten. The bulk of the energy of the electrons is dissipated at the target in the form of heat, but a small fraction of their energy (of the order of one-tenth of 1%) is converted into X-rays. One of the main problems in the design of high-power X-ray tubes is the provision of adequate means for carrying off the heat generated at the anode. On account of the high rate of production of

23rd January, 1940 (Vol. XIX, No. 2, February, 1940).

heat, the electrons must be allowed to impinge on a fairly large area of the target (known as the focus or "focal spot"), so that the source of the X-rays is comparatively large, and this imposes a limitation on the fineness of detail which can be revealed by radiological examination.

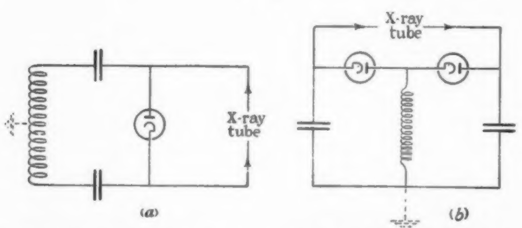
X-ray tubes may be operated either by constant potentials or by alternating potentials. In the latter case some form of rectifier is usually desirable to decrease the electrical strain on the X-ray tube.

In the case of single-phase power supplies, either half or full-wave rectification may be used. The circuits employed are exemplified in Fig. 1 where (*a*) is a half-wave rectifier and (*b*) a full-wave rectifier. Circuits of this type are frequently used to produce peak



High-tension generator with half-wave rectification. **High-tension generator with full-wave rectification.**

Fig. 1.



High-tension generator of the Veilard (pulsating volt.) type. **High-tension generator of the Greinacher (con. volt.) type.**

Fig. 2.

voltages up to 120 kV or even 150 kV, such as are suitable for the examination of light alloys and of ferrous materials and brasses not thicker than about 1 in. For the radiographic examination of thick steel or brass objects, voltages of 200 kV peak and over are required. Such voltages are usually produced by voltage-doubling circuits such as the Villard pulsating voltage circuit (Fig. 2a), or the Greinacher constant voltage circuit (Fig. 2b). The principle

of voltage-multiplying may be carried much farther, and has been used for producing voltages up to 1,000,000 volts.

Properties of X-rays.

By means of suitable diffraction gratings, whether in the form of crystals or of ruled gratings, it is possible to analyse an X-ray beam and so determine its constitution. In general an X-ray beam consists (like white light) of a wide spectral range of different wave-lengths, shown diagrammatically in Fig. 3, bounded on the short wave-length side by a clearly defined limiting wave-length, the value of which depends solely on the maximum velocity of the

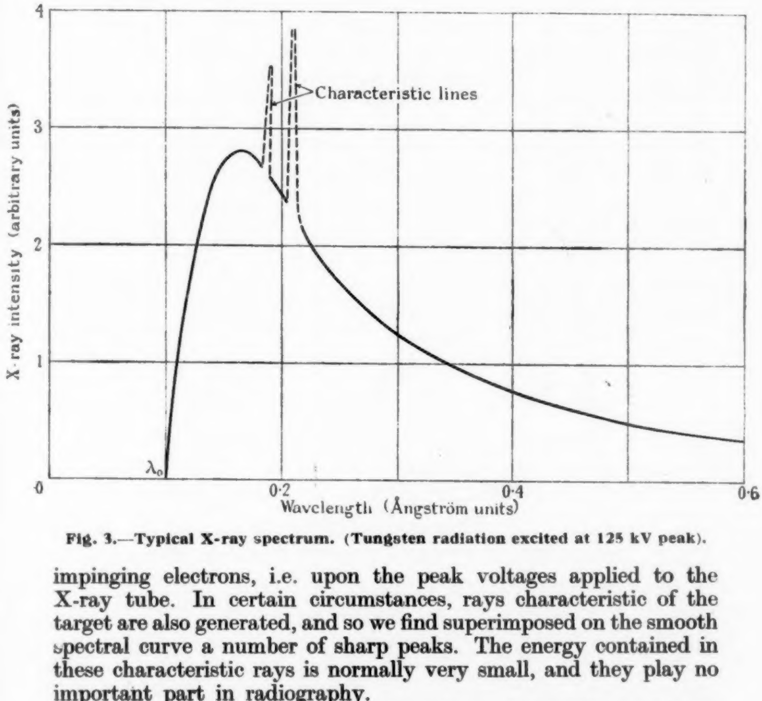


Fig. 3.—Typical X-ray spectrum. (Tungsten radiation excited at 125 kV peak).

impinging electrons, i.e. upon the peak voltages applied to the X-ray tube. In certain circumstances, rays characteristic of the target are also generated, and so we find superimposed on the smooth spectral curve a number of sharp peaks. The energy contained in these characteristic rays is normally very small, and they play no important part in radiography.

The wave-lengths of X-rays commonly used for radiography are of the order of magnitude from say 0.5 Angstrom units to 0.05 Angstrom units (one A.U. = 10^{-8} cm. = $\frac{1}{250000000}$ in.), while the wave-lengths of radiation in the visible spectrum lie between 3,500

and 7,000 A.U. The wave-lengths of light rays are large compared with the spacings of the atoms in ordinary matter, so that for the purpose of reflecting and transmitting light, matter may usually be regarded as continuous and this provides the essential requirement for the well known laws of reflection and refraction. In the case of X-rays the wave-lengths are of the same order as the distances separating atoms, and on this account there is in general no reflection or refraction of rays in the usual manner, although very long-waved X-rays have, in certain experimental conditions, been reflected and refracted just like ordinary light. It is therefore impossible to construct lenses to focus X-ray beams, and in radiography we have unfortunately to be content with shadow pictures.

When X-rays pass through matter, they are absorbed to a greater or less extent, and the differential absorption of the rays constitutes the basis of radiographic examination. In general (*a*) X-rays excited at high voltages have shorter wave lengths and are less easily absorbed than those excited at lower voltages, and (*b*) light elements (more strictly, elements of low atomic number) are less absorbent weight for weight than heavy elements. We may note that the filtration of rays through sheets of material decreases the average

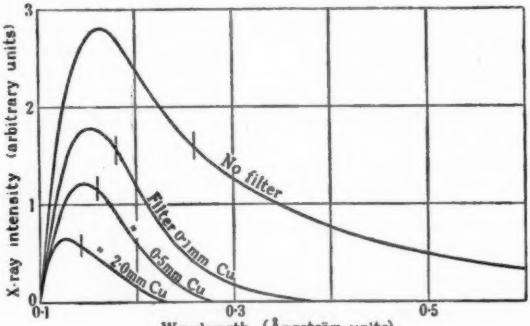


Fig. 4.—Effect of filtering on spectrum of an X-ray beam.

wave-length, and therefore increases the penetrating power of the beam, a fact which has a bearing on the technique of radiological examination in certain circumstances. Fig. 4 shows the amount and composition of the radiation emitted by an X-ray tube, both unfiltered and when transmitted through copper sheets 0.1, 0.5, and 2.0 mm. thick. The curves show that not only is the total quantity of radiation (the area under the curve) reduced progressively by filtration but that the longer waves are reduced in intensity to a greater extent than are the shorter waves.

In addition to being absorbed, X-rays passing through matter are also "scattered"—that is, their directions are changed. This property is roughly analogous to the scattering of light by fog or in passing through a turbid medium. In general, X-rays of short wave-length suffer more scattering than rays of long wave-length, and it has been shown by Compton that the scattered radiation has somewhat longer wave-length than the incident radiation.

X-rays are capable of blackening photographic emulsions, the laws of this photographic action being essentially similar to those which hold for the blackening by visible light. They are also capable of producing fluorescence in certain materials, notably barium platinocyanide, calcium tungstate, and zinc sulphide. This property is turned to account in two different ways. Firstly, the fluorescent image of an object under examination produced on screens coated with grains of fluorescent salt may be used directly as a rapid but somewhat insensitive means of detecting flaws or checking assemblies, and secondly, the visible light emitted may be used to enhance the direct photographic action of the rays, and so permit X-ray pictures to be taken in a shorter time. Salts which fluoresce with a white or greenish-white light are used for fluoroscopic screens, while salts which fluoresce with blue light are more effective as photographic intensifying screens on account of the higher actinic value of the light emitted.

Unfortunately, it seems to be a general rule that very sensitive materials, whether photographic films, fluorescent screens or intensifying screens, are more grainy than materials of moderate sensitivity.

X-ray Protection.

It has been known for some time that undue exposure to X-rays leads to a deterioration of the health of operators, and it is the obvious duty of those in charge of X-ray departments to take such steps as are necessary to avoid this danger. The matter has been thoroughly studied by the International X-ray and Radium Protection Commission and by the British X-ray and Radium Protection Committee, each of which has issued comprehensive recommendations* dealing with the subject. These recommendations deal primarily with the use of X-rays in hospital radiological departments, but are also applicable to the majority of conditions under which X-rays are used for industrial and research purposes.

The dangers arising from X-ray work may be due to three main causes, namely (1) the direct action of the radiation, (2) the effects of nitrous fumes produced in the atmosphere by the high-tension

* Copies of these recommendations may be had on application to the Director, the National Physical Laboratory, Teddington, Middlesex.

equipment used and, in some cases (3) the electrical risks associated with the operation, often in the dark, of apparatus working at many thousand volts and having high-tension conductors which are somewhat exposed.

As regards protection from the direct action of the radiation, the essential point is to enclose the X-ray tube as completely as possible with absorbing material, except of course for the aperture necessary to permit the egress of the direct beam of X-radiation, and then to take suitable precautions to prevent radiation scattered by the air,

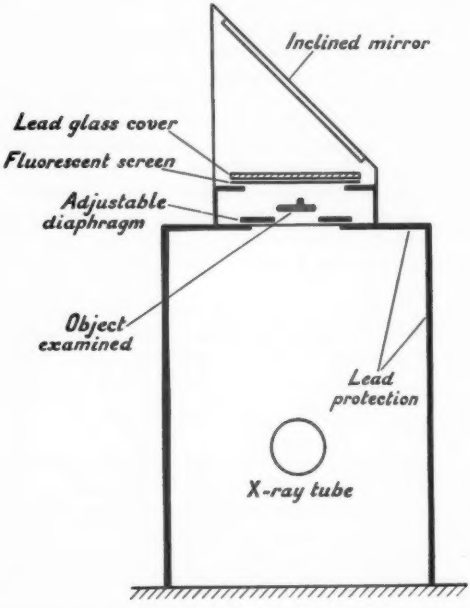


Fig. 5.—Diagram of a protected fluoroscopic examination bench.

the objects radiographed, tables, etc., from reaching the operators. In most modern X-ray tubes, a protective lead cylinder is actually built into the tube itself, so that there is rarely need for further protection from direct radiation. Operators may be protected from scattered radiation by providing a control-cubicle lined with lead sheet or, in many cases, by mounting lead screens near to the objects under examination. In general, lead sheet two mm. in thickness provides adequate protection.

Fluoroscopic screen examinations call for more protection, particularly if these are carried out on a large scale, as in the routine examination of large numbers of small objects. Operators normally work nearer to the X-ray tube and for longer hours, having regard to the type of work, than in hospital practice. The protection afforded by the tube itself should therefore be increased by enclosing the tube in a box covered with, say, two mm. lead sheet, while the fluorescent screen, covered with lead glass in the usual manner, should whenever possible be viewed indirectly by means of a mirror. Fig. 5 shows diagrammatically a suitable arrangement for a fluoroscopic examination bench. Further, in this type of work special care should be taken to prevent the exposure of the hands of operators to X-rays. This might be done by the use of lead-rubber gloves, but these would almost certainly be found inconvenient when small objects are handled ; long forceps or mechanical devices adapted to the particular work will usually be found more suitable. In general, it is better practice to build the protective devices into the apparatus itself than to encumber operators with heavy protective gloves and aprons.

Adequate ventilation and the possibility of opening up rooms to daylight and fresh air are essential requirements in all X-ray rooms. The development of shockproof X-ray tubes and cables suitable for all voltages normally used in radiography has greatly reduced the electrical dangers, and in a well-planned and equipped X-ray department there should be little risk of serious electrical shocks. Improperly designed apparatus has a tendency to develop static charges at various points, and although these are usually more disconcerting than dangerous, they should be eliminated by suitable earthing.

The Principles of Radiography.

In the brief outline of the more important properties of X-rays, it was pointed out that a radiograph is essentially a shadowgraph produced by a source of radiation of finite size, and showing details arising from the different absorbing powers of different parts of the object radiographed. To take a specific example, let us consider a spherical cavity filled with air in a block of heavier material, e.g. iron or aluminium. The experimental arrangements for making the radiograph are shown diagrammatically in Fig. 6, which illustrates a source of X-rays emitting radiation some of which passes through the block on to a film placed as nearly as possible in contact with the block. Fig. 6a, shows a hypothical arrangement in which the X-rays originate from a point source. In this case the shadow produced on the film has sharp edges, and the possibility of revealing the defect depends solely on the production of sufficient contrast on the finished film to be visible. A point-source of radiation cannot

be realised in practice, the focal spots of actual tubes ranging from, say, 1.5 mm. for low-voltage tubes to nearly 10 mm. in the case of high-voltage tubes, but a source of finite size can be made to approximate to a point source from the geometrical point of view by working with large focus-film distances. However, the time of exposure necessary to produce a radiograph of sufficient density increases roughly as the square of the focus-film distance so that a practical limit is soon reached.

In most cases we have a state of affairs depicted in an exaggerated form in Figs. 6b and 6c. It will be seen that the radiograph shows a central dark shadow surrounded by a penumbra, dark on the inside and becoming lighter towards the geometrical edges. If the defect is a cavity which is smaller than the focus, a condition usually

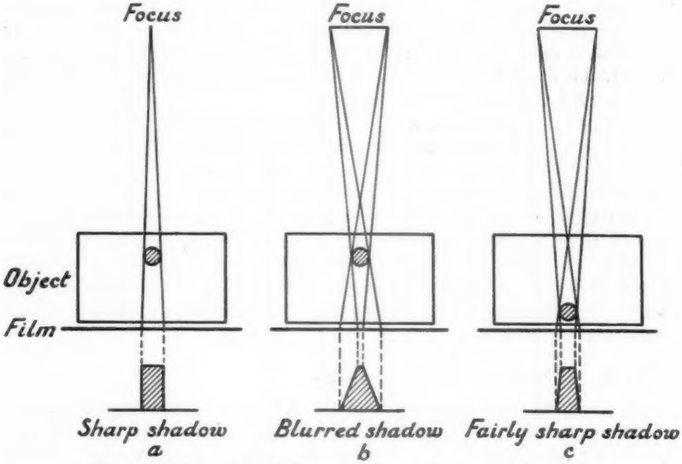


Fig. 6.—Effect on definition of an X-ray focus of finite size.

present in industrial radiography, the central shadow is less and the overall size of the penumbra greater than the size of the cavity itself. It is also clear from the diagrams 6b and 6c that the nearer the cavity is to the film the better is the definition. Now it is a known fact that the eye can appreciate smaller differences in contrast when the edge between the lighter and darker portions is sharp than when there is only a diffuse edge, so that this geometric " blurring " increases the size of the smallest defect which is revealed on the radiograph or reduces what we may define as the " resolution " of the radiograph. Reference has already been made to the

blurring of details due to purely photographic processes, arising from the inherent graininess of photographic emulsions and intensifying screens, and there appears also to be some additional blurring due to scattering of the radiation in the film itself. These factors, which are largely outside the control of the X-ray worker, put a limit on the resolution of the radiographs. Although it is difficult to ascribe definite values, it appears that the photographic blurring arising in double-coated films wrapped in the usual manner in double envelopes may be of the order of 0.1 mm., while in the case of fast combinations of films and screens it may be as much as 0.5 mm.

We have thus two causes of blurring, one due primarily to the finite size of the focus of the X-ray tube, and one due to photographic causes. Blurring due to the first cause may be reduced by increasing the focus-film distance and increasing the time of exposure to compensate for the decreased amount of radiation, but there appears to be no advantage in adopting arrangements in which the geometric blurring is less than the inherent photographic blurring. The present evidence suggests that at focus-film distances of between 20 and 30 in., the geometric blurring of the shadow of an object about 1 in. from the film is of the same order of magnitude as the inherent photographic blurring, assuming that the size of the focus and the type of intensifying screen are chosen to suit the particular work in hand. The use of fairly short focus-film distances may result in some distortion of the image, but this is rarely a serious disadvantage and, in certain circumstances, may actually prove advantageous.

When the sharpest possible shadow has been obtained, the resolution of the radiograph is determined by the degree of contrast between the shadow of the defect and the background. Within limits, the degree of contrast is within the control of the radiologist, for in general it is greater the lower the exciting voltage on the X-ray tube, but the use of lower voltages involves longer exposure times, and again there is a practical limit. If the object under test has areas of very different thicknesses, e.g. a casting of irregular shape, or a plate with a boss, it may prove impossible to radiograph it with a single exposure, and several radiographs, each depicting a relatively small range of thicknesses will be necessary. In radiographic work in which the finest detail is not required, the range of thicknesses which can be shown on a single radiograph may be increased by working at a voltage suitable for the penetration of the thicker parts and filtering the X-ray beam by, say, one or two mm. of copper so as to make the X-ray beam more homogeneous. This artifice reduces the contrast and often enables readable radiographs of both thinner and thicker parts to be made on the same film.

The degree of contrast is also seriously influenced by the effect of scattered radiation in a manner depicted roughly in Fig. 7. If, for the purposes of illustration we assume the defect to be quite

opaque to the radiation, it is obvious that the radiograph produced by the direct beam would consist of a clear area in a uniform background. However, as has already been mentioned, X-rays in passing through matter are scattered in all directions, and hence, as shown in the diagram, some radiation is scattered into the shadow of the object, blackening the film and reducing the contrast between the shadow of the object and the background. Edges are particularly prone to give rise to scattered radiation.

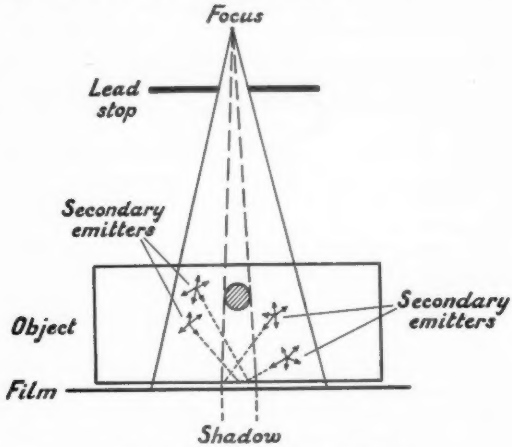


Fig. 7.—Effect of scattered radiation.

The reduction of scattered radiation is one of the most important experimental details in radiography. Since scattering is largely a volume effect, the amount of scattered radiation may be reduced by using the smallest possible X-ray beam and by absorbing X-rays scattered at the edges by wrapping the object in lead, or immersing it in suitable powders or absorbing liquids, such as lead-acetate or barium chloride solutions. Similarly, large surface-cavities and holes give rise to scattered radiation which may be reduced by filling them with, say, a paste of vaseline and litharge. In spite of all these precautions the effects of scattered radiation may still mask the details, particularly in thick objects, the radiography of which involves the use of X-rays excited at high voltages, and steps must be taken to prevent scattered radiation reaching the film. This may be done in two ways, one by interposing a sheet of lead a few thousandths of an inch thick between the object and the film, and the other by interposing a mechanical device known as a Potter Bucky grid. The first method takes advantage of the fact that

scattered X-rays are of longer wave-length and are therefore more easily absorbed than the direct rays. Incidentally, lead screens placed on each side of the film have a marked intensifying effect, and a technique involving the use of such screens probably provides the finest-quality radiographs in the case of thick objects. The Potter-Bucky grid consists of a lattice of alternate strips of lead and wood or other transparent material and serves to prevent X-rays from reaching the film unless they appear to have come from the focus of the tube; some multiply-scattered X-rays have the same direction as the primary rays, and these are, of course, not intercepted by the grid. In use, the grid is kept moving so that its shadow does not appear on the radiograph. A similar device, useful in some cases, is the Lysholm grid which is essentially like a Potter Bucky grid but has very fine opaque and transparent strips, and is not kept moving. Radiographs taken with a Lysholm grid show the fine grid-lines, but in practice these do not interfere appreciably with the reading of the film.

Detail Revealed by Radiography.

For the purpose of estimating the finest details which may be revealed by radiography, the more important flaws encountered in the testing of materials may be classified into three main groups: (1) Those having comparable dimensions in all directions, such as blow-holes, inclusions, and shrinkage cavities; (2) those having two dimensions much greater than the third, typified by cracks, and (3) those having one dimension much greater than the other two, "pipes" in castings being typical examples. The essential distinction between the various groups is that whereas defects of the blow-hole type give substantially the same radiographic picture, whatever the direction of the X-ray beam, the radiographic appearance, and hence the discernibility of many types of cracks depends to a large extent on the direction of the X-rays relative to the least dimension of the crack. Defects of the pipe type fall between the other two classes and have features in common with both.

As regards cavities, it is a matter of experience that in reasonably favourable cases defects having dimensions of 1% or even less of the thickness of the material can be detected, while in the case of thick specimens of heavy metals and objects whose form makes radiography difficult, proper experimental arrangements can usually be made to reveal defects having dimensions 3% of the thickness over a considerable area. Only in exceptional cases is it impossible to show defects as great as 5% of the thickness. Porosity of the type consisting of large numbers of very small, almost microscopic cavities is often shown as a somewhat diffuse general darkening, but if such a porosity extends over the whole area radiographed it cannot always be detected radiographically.

The visibility of cracks depends jointly on their direction relative to the X-ray beam and their depths and widths. From the radiographic point of view, cracks may be divided into two types, those in which the crack depth is much greater than the width (" deep " cracks) and those having depth and width of the same order of magnitude (" shallow " cracks). If a deep crack lies accurately in the direction of the X-ray beam, it can be shown easily, but the visibility of a deep crack making an angle to the beam depends, as Warren* has pointed out, on the projected area of the cavity in the direction of the X-ray beam. As typical, Warren has shown that, under good conditions, a deep crack 0.001 in. wide can be detected in a steel plate 2 in. thick if its direction makes an agle not exceeding about 5° to the X-ray beam, while a crack 0.004 in. wide is visible up to angles of 25° with the beam. These angles are approximately doubled if the steel plate is only 1 in. thick. In the case of shallow cracks, the essential factor is the area of cross section, and the appearance of the radiograph is nearly independent of the direction of the X-ray beam. Warren has shown that the visibility of a shallow crack is the same as that of a cavity or an excrescence having the same area of cross section. Thus, if the conditions are such that a cavity or excrescence 0.01 in. in diameter can be detected, a shallow crack having the same cross-sectional area (about 0.0001 sq. ins.) can be revealed, and it is immaterial whether the crack is, say, 0.002 in. wide and 0.05 in. deep, or 0.01 in. wide and 0.01 in. deep.

Pipes may be regarded, from the radiographic point of view, as elongated blow-holes and are discernible on the picture if their projected area of cross section in the direction of the X-ray beam exceeds the limit of resolution of the radiograph. In general, fine pipes are more easily discerned than blow-holes of the same diameter since their relatively great length tends to make geometric blurring less important.

Radiological examination is in general unsuitable for the detection of fine hair-cracks and pipes which sometimes occur in forgings. These often result from the elongation and compression of cavities in the original billets, and the possibility of this occurrence may be reduced by examining the billets before forging operations are commenced, and rejecting unsuitable ones.

Whenever possible a radiograph should afford a definite indication of the degree of resolution. This is best done by radiographing some standard object, often referred to as a " penetrometer " simultaneously with the object under examination. Various representative bodies have attempted to specify forms for penetrometers, but no standard form has as yet been laid down. At the National

---

* Warren. *Brit. Journ. of Radiology*, VIII, p. 235, 1935.

Physical Laboratory, two forms of penetrometer are used, often simultaneously, one consisting a step-wedge and the other of a series of short wires of different diameters. In each case the penetrometer, which is whenever possible made of the same material as the object under test, is placed on the object and between it and the X-ray tube, so that the shadow of the penetrometer appears on the radiograph. The dimensions of the least penetrometer step visible serve to indicate the size of the smallest cavity or crack which could be detected with the radiographic technique adopted.

A radiograph is essentially a plane projection of defects which are distributed in space throughout a body, and in general a single radiograph gives no indication of the depth of the defect below the surface. If, however, two radiographs are taken on the same film, the X-ray tube being moved through a suitable distance between the exposures, there appear two traces of each defect and, knowing the separation of the images, the focus-film distance, and the tube shift, the distance of each defect from the film may be found by simple geometry.

By making the radiographs on different films and examining them by means of suitable instruments, it is possible to secure stereoscopic effects, while by using suitable experimental arrangements it is possible to examine different layers of a body, and thus avoid a certain amount of confusion in the radiograph.

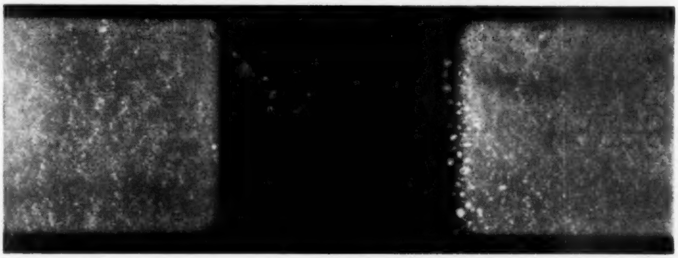


Fig. 8.—Radiograph of a light alloy die-casting, showing blow-holes, inclusions, and inter-crystalline porosity.

Some Typical Radiographs.

Although objects submitted for radiographic examination differ widely in form and are fashioned from different materials, the same types of defects tend to occur and, with experience, it is not difficult to identify the defects speedily from the appearance of the radiographs. A few examples from work carried out at the Nationalf Physical Laboratory will illustrate the radiographic appearances of the more common flaws.

Fig. 8 shows a radiograph of a portion of a light-alloy die-casting having several typical flaws. In the middle of the casting was a thickened portion and a strengthening rib. In the figure, which is made from a print of the radiograph, the thickened portion appears darker than the remainder of the casting. At the right-hand edge of the thickened portion are a number of light roughly circular patches which indicate the presence of blow-holes, while towards the left of this portion are light irregular marks characteristic of inclusions, in this case probably of oxide. The thinner portion of the casting shows a fine inter-crystalline porosity.

Fig. 9 is a radiograph of a portion of an aluminium cylinder-head from a motor car engine, revealing a conspicuous crack terminating at its lower end in an elaborate delta of finer cracks, not all of which

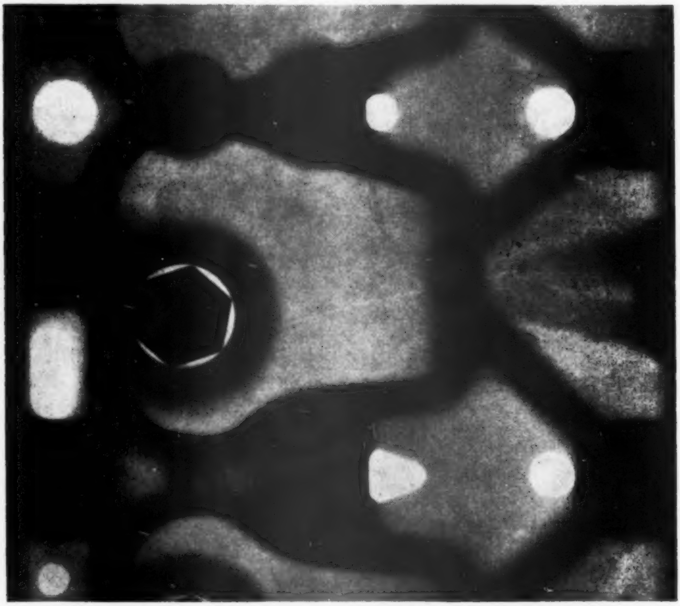


Fig. 9.—Radiograph of part of an aluminium cylinder-head, showing a system of cracks and some inclusions.

are reproduced in the illustration. There are also several inclusions of material heavier than aluminium, and a certain amount of coarse porosity.

Fig. 10 shows a photograph of a steel casting together with a radiograph of part of it. Viewed externally, the casting appeared to be satisfactory, but radiographic examination showed that it had many cavities including one very large one, visible at the left

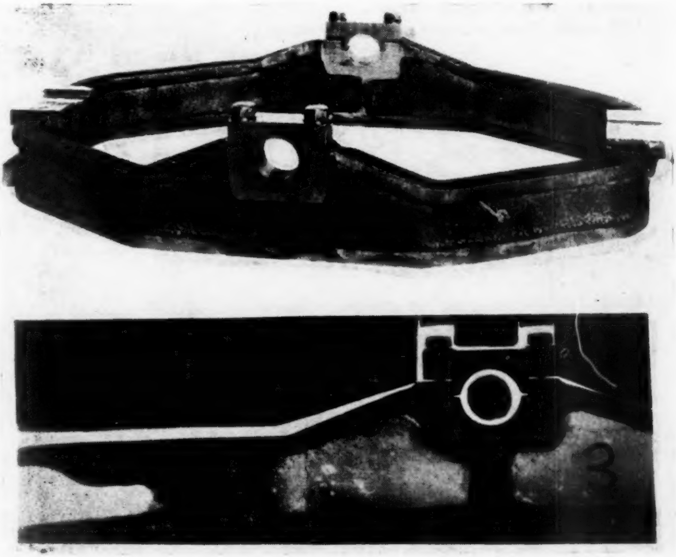


Fig. 10.—Photograph of a steel casting and radiograph of part of it. The radiograph shows a large blow-hole (left) and many smaller cavities.

hand side of the radiograph. Further examination showed that only a very thin film of metal covered this cavity, which extended nearly through the thickness of the casting.

The radiographic appearances of the most common defects in V-welds are shown in Fig. 11. In Fig. 11a there is a lack of fusion along one face of the V, in Fig. 11b the welding metal has failed to penetrate to the bottom of the V, while in Fig. 11c improper conditions have resulted in serious oxidation, and the weld shows large oxide inclusions and some cavities. Another example of faulty welding is given in Fig. 12, which relates to a welded gas cylinder which had burst in use (Fig. 12a) with fatal consequences. The cylinder had several welds, and radiographs of two portions are shown. The radiograph of part of the longitudinal weld (Fig. 12c) shows traces of oxidation and a few large cavities, while there

is also a line of fine cavities down the middle of the V. Fig. 12b relates to part of the longitudinal weld and part of the circumferential weld. The longitudinal weld had the same defects as those shown in Fig. 12c, while the radiograph of the circumferential weld shows gross defects, including very poor fusion between the parent metal and the welding metal.

Although X-rays are used most commonly in the examination of metallic objects, their use is by no means restricted to these.

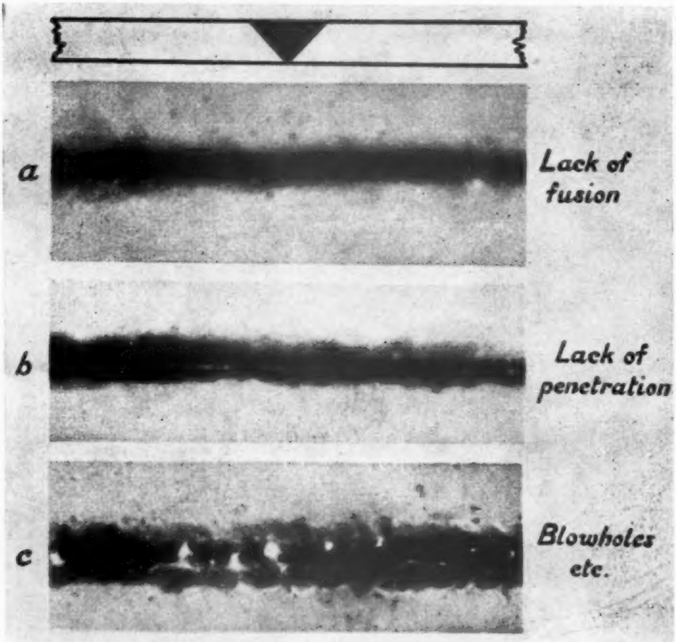


Fig. 11.—Radiographs of common defects in V-welds.

Cavities, inclusions, and cracks occur frequently in ceramic and other baked articles, their radiographic appearances being similar to those typified in the preceding examples. As an example, Fig 13 shows a radiograph of a portion of a bauxite grinding wheel which reveals a series of radial cracks and some heavier inclusions, the radiographic appearances of which are very similar to the corresponding defects in cast aluminium shown in Figs. 8 and 9.

Some Limitations of Radiographic Examinations.

We have seen that, although radiographic examinations are capable of giving much reliable information as to the soundness of objects, a thorough examination requires a great deal of skill, patience, and photographic material, and consequently adequate

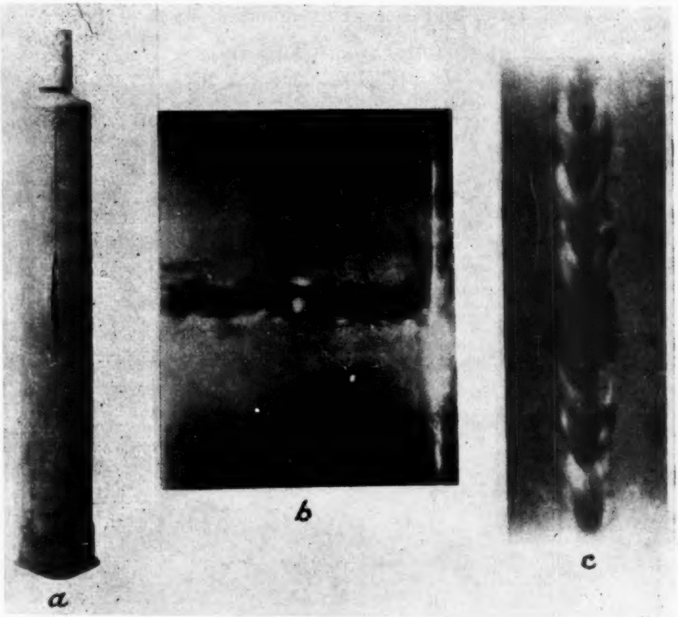


Fig. 12.—Radiographs of faulty welds in a gas-cylinder which burst in use.

radiographic examinations are apt to be costly. As Pullin* has pointed out "The development of radiological methods has indicated that except in certain special cases radiology will not find its maximum value in routine inspection. Radiography may be found to be primarily a consultive method of examination and its proper place would appear to be the foundry and the machine shop." The exceptions to the rule are many, but fall into two main groups (*a*) cases in which the failure of a component is likely to endanger life or to imperil larger structures, and (*b*) cases in which the material

* Pullin. "Engineering Radiography," Bell, London.

in question can, on account of its size, form, or substance, be examined without great expense.

In the first group it is obvious that so reliable an aid to inspection as X-rays cannot be neglected, and as extreme examples, thorough radiographic examinations have been made of welded bridges and of the Great Boulder Dam, while vital parts of aircraft have for long received 100% radiological examination in most countries. In all such cases the expense of examination is clearly justified.

Fig. 13.—Radiograph of part of a bauxite grinding wheel, showing cracks and inclusions.

As examples of the second group, which includes objects easily inspected radiographically we may consider especially those which permit of rapid examination fluorescopic methods, such as small light-alloy castings and assemblies such as golf-balls, fountain pens, shot-gun cartridges, and rubber soles for footwear. In all these cases inspection may be carried out at a high speed (500 to 1,000 per hour) by loading the objects on a belt which moves continuously under the fluorescent screen.

Other types of materials lend themselves to sample-testing to ensure that the standard of workmanship originally approved is

being maintained. This applies particularly when large numbers of similar objects are made. To take a specific example, in die-casting X-rays prove an invaluable aid in the development of suitable dies and an appropriate technique, but by recourse to X-ray tests, often of a simple nature, the production engineer has at his disposal a means of ensuring that his carefully-developed technique is being adhered to under actual production conditions. In such circumstances, it is usual to make a radiographic inspection of the first ten or twenty castings and afterwards of, say, 2% or 5% of the output. Similar considerations apply to welds, where again X-rays are of service both in developing a suitable technique and in ensuring that it is maintained. Incidentally, it is often claimed that the psychological effect of X-ray inspection leads to improved production, and it is a matter of common experience that the manufacturers who adopt such inspections find the percentage of faulty articles greater than they expected.

If radiographic examinations are to obtain the maximum efficiency, it is essential that there should be the closest possible collaboration between the various interested departments, such as design, production, and inspection. The designer can often indicate which areas of, say, a casting, will be subjected to stress, and the radiographer can then devote his special attentions to this area, often making a more useful examination at lower cost than if he attempted to examine the whole casting in less detail. Similarly, X-ray examinations can often be of great help in the production side, by assisting in the rejection of unsuitable primary material and the development of suitable techniques. Conversely, the production engineer can assist the radiologist to carry out his work economcally by indicating the types of defects likely to occur, or the types in which he is specially interested. We have seen, for example, that the detection of fine cracks requires many more radiographs from different angles than does the detection of blow holes and inclusions, and it follows that, if a given material is known to be prone to develop blow-holes while fine cracks practically never occur it would, in many cases, be a waste of time and material for the radiographer to make his examination sufficiently thorough to detect cracks.

It cannot be too strongly emphasised that the X-ray worker, as such, cannot determine whether the object radiographed is or is not suitable for the purpose for which it is intended. This decision must rest with an inspector who has at his disposal information concerning the use to which the object will be put, and can estimate the effect of the various flaws revealed radiographically having regard to their location and the known effect of such flaws on the strength of the structure. In many cases the radiologist will have had the necessary technical training and experience, and will be

given the relevant data from other departments, and in these circumstances he can effectively combine the duties of radiologist and inspector.

Summary.

This paper deals mainly with the uses and the limitations of X-ray examinations of various types of materials. The production and properties of X-rays, in so far as these have a bearing on radiographic technique, are briefly discussed, and this discussion leads to a more detailed study of the various factors influencing the fineness of resolution of radiographs, and the precautions necessary to ensure that the maximum possible resolution is obtained. It is shown that in most cases voids having dimensions of 1% of the thickness of the material can be detected, while the conditions affecting the discernibility of cracks are considered in some detail.

The radiographic appearances of the defects most commonly encountered are exemplified by means of typical radiographs, with particular reference to castings and welds.

It is concluded that, while X-ray examinations may be of great use in inspection, their maximum effectiveness can only be realised by close collaboration with the designer, producer, and inspector. In general, X-ray inspections are too costly for 100% inspection, unless this is justified by other considerations such as danger to life or the jeopardising of larger structures. Certain cases arise, however, in which X-ray examinations can be carried out by fluoroscopic examination alone, and in these cases 100% inspection can be undertaken expeditiously and cheaply. In other cases where large numbers of similar articles are made, radiological inspection of, say, 2% to 5% of the production is usually justifiable, particularly if it is desired to ensure that carefully-developed technique are being adhered to in production.

Discussion

MR. SCHALL: I have very little to add after the excellent and complete survey that Dr. Bell has given you on this subject, but there are one or two points he made that I would like to underline. The first is that the X-ray equipment for inspection is absolutely safe to-day. That used not always to be the case, but it is now perfectly shock-proof. You have to put yourself into the hands of people you can depend upon, but when you do that then there is no danger in the use of the equipment.

As regards the use to which X-rays can be put, there are the two that Dr. Bell mentioned—namely, what one might call the examination of material defects such as cracks and blow-holes in the castings, and also—and this is the case particularly in manufacturing—faulty welding. There is one he did not mention, because it does not really come into the purvey of such a meeting as this, but I would like to touch on it, and that, of course, is the very large field of the examination of the crystal structure of materials. It is not a subject that would come into the hands of a production engineer, but it is a subject which has an enormous bearing on the type of material you use in engineering work and is of ever-increasing importance. It is a field where the use of X-rays is probably more productive of useful results than in any other. This, as I say, does not really come within the ambit of the production engineer.

As regards the examination of work for blow-holes and cracks, that is probably the most difficult form of X-ray examination. Dr. Bell has told you that to locate a crack you have to look at it from more than one angle, because if you pass the radiation at an angle to the plane of the crack you have got nothing: you have got to pass it in the plane of the crack. The plane of the crack has got to be at right angles to the film on which you are making an exposure: otherwise you do not see it. Not only does that occupy a lot of time, but it is extremely expensive. The making of radiographs of such cracks is a delayed and costly procedure and can only be resorted to in castings or pieces of work that are really of paramount importance and cannot be easily or inexpensively replaced. The stress that has been put upon the use of X-rays in locating cracks and blow-holes and so on is to some extent, I think, the reason why the use of X-rays has not become more general in the examination of work generally. It becomes obvious at once to anybody who looks into the matter at all that it is a work that can only be carried on at a place like the National Physical Laboratory or some other well-equipped and big laboratory, but cannot easily

be carried on in ordinary works except those of a very big and wealthy firm.

But there is a field of examination where the work-piece can be examined, as Dr. Bell told you, on the fluorescent screen on a travelling belt, and I will just mention a few instances. He has already told you of the golf ball. Well, the golf ball has a core which is denser than its envelope, and if that core is not central the flight of the golf ball is likely to be erratic, and therefore in some factories the golf ball is passed in front of an X-ray machine and examined on a fluorescent screen to make sure that that core is central. Now next time you don't sink your putt you will know that that ball was not examined by X-ray.

The next type of material or work that comes to my mind is bakelite used for insulating purposes, and particularly mica used for insulating purposes. When that is put into lead pipes for high tension transformers or for tubes to insulate the primary from the secondary of a transformer it has no appreciable tension. If there is in the bakelite or the mica any trace, even the smallest, of metallic substances under the stress of the electricity it will spread and gradually break down the insulation of that tube. For that reason one factory that I know of examines its mica or bakelite tubes for that purpose under X-rays to make sure that there is no metallic material present. That can be done on a fluorescent screen, because the difference in the opacity of the X-ray in relation to the mica or the bakelite and the little piece of metal is so great that you very easily see the metal on the screen.

Another instance of a work-piece that is examined is somewhat similar to the one that Dr. Bell showed you of the shot-gun, and I think it is due to Dr. Bell himself that this work was perfected. I think I am right in saying that it was he who developed a system for the mass examination of these fuses at Woolwich. There a whole series of them is put into a semicircular holder and a piece of bromide paper is put behind. At the centre of the semicircle is an X-ray tube, an exposure is made, and you have a string of these fuses radiographed on to the paper, which is developed to see whether some particular part inside the fuse is in position, because if it is not there the fuse is no good.

Still another example, of course, which is not really an engineering product, is the ordinary periscope which you find in bootmaking shops. No doubt the same sort of principle can be extended from the bootmaking industry, to see that nails and so on are in their proper position. That kind of examination can be extended very considerably on mass-produced articles where you want to find the correct position of something or other inside the articles after they have been made and you cannot locate or detect in any other way. Such mass-produced articles can be rapidly examined on a

fluorescent screen, and the equipment nowadays is quite safe and can be made to run for hours on end. Comparatively unskilled labour can see these things coming by, and they are trained to look for one particular feature.

Mr. N. V. Kipping (Section President, in the chair): I would like to ask for some idea of the cost of these machines, particularly where the problem might be solved on a fluorescent screen.

Mr. Schall: It is a hard question to answer. The X-ray equipment for a hospital is always nicely chromium-plated and finished off. The cost depends so very much on the particular purpose for which it is wanted, but something from £300, £400 for equipment, producing up to about 1,000 volts, would cover it. Of course, if you want to go into steel up to 2,000 volts you would find it would cost up to about £1,000, but the equipment for comparatively soft materials such as I have mentioned is covered by £300 or £400.

Mr. N. Gerard Smith proposed a vote of thanks to Dr. Bell for his lecture.

AUSTRALIA AND THE WAR

Speech by the President of the Sydney (New South Wales) Section.

MR. E. C. PARKINSON, President, Sydney (New South Wales) Section, speaking at a meeting of the Institution held in the hall of the Royal Empire Society, Sydney, on Tuesday, September 12, 1939, before introducing the lecturer of the evening, Mr. G. O. Ingledew, A.M.I.P.E., said: Since our last meeting we have all heard those fateful words of Mr. Chamberlain that war has been declared. At this time last year, with Mr. Finlay, I was in England. We spent some months there inspecting engineering organisations in all parts of England, and I must say we were greatly impressed with what the production engineers had done. Since then there has been another twelve months of great activity. After Munich there was no easing up at all—rather the reverse. We feel that Great Britain is far better prepared now than she was in 1914, and that we can look forward with every confidence to final victory.

Before that victory is attained, however, the engineers of the whole of the British Empire have to face their greatest task—supplies for the fighting forces on a scale undreamt of, even in the war of 1914-18.

In the last war, we had the men, but those of us who had a taste of it know that we were sadly lacking, in the early days, those supplies so essential for victory. This time, we have not only the men, but ample supplies.

We here feel that we are so far from the centre of activities. Everyone wants to be on the job, doing something to help—that overnight our factories should be changed over to produce munitions. But much as we might desire it, it cannot be. The Defence Machine is a very big one, and will take some considerable time to get moving. A vast amount of work has already been done—machinery has been landed in Australia to produce all manner of things. Some of its is producing, and more will be in operation very soon. Thanks to the foresight of our Defence Authorities and the development of private enterprise, we shall be able to play a far greater part in the production of war materials than in the last war.

The Minister for Supply and Development says that until all existing defence factories, plus the many annexe units planned, are fully in production, there can be little call on private enterprise,

and that the most useful thing they can do at this stage is to carry on—business as usual.

Some of our members are already very actively engaged, and we feel that it will not be long before all members of this section are playing the part they are so keen to play. Members in Great Britain have already done a great job, and will continue to do it under conditions of extreme difficulty.

Your committee felt that we, as the first Overseas Section of the Institution of Production Engineers, should send some message of greeting to our members in Great Britain, and we propose, with your approval, to send the following message to the General Secretary—

> "Sydney Section sends good wishes to all members in England, and its assurance that all Australian members appreciate the good work they have done and will continue to do in the difficult times ahead. Australian members are with you wholeheartedly and will do everything possible to ensure victory."

I am sure, gentlemen, that that expresses your feelings at this time.

THE MANUFACTURE OF TINPLATE CONTAINERS

Paper presented to the Institution, Sydney (New South Wales) Section, by G. O. Ingledew, A.M.I.P.E.

Introduction.

A LITTLE thought admits of three reasons for the presentation of this paper. In the first place the subject is one outside the usual ambit of the members and, therefore, the novelty may strike a note of interest. Secondly, the canning of goods and foodstuffs particularly, is playing an increasingly important role in our lives, and it is therefore the policy of wisdom to know a little about it. The study of dietetics has become an exact science, and it has recently discovered something of the nature and tremendous importances of the various vitamins. It has been found that in many foods these vitamins are lost to a large extent by cooking in the usual household manner. This is due, partly, to the great amount of water usually used, but more largely, to the withering which occurs during the time which elapses between the picking of fruit or vegetables and their receipt by the householder.

The methods of a modern hygienic canning plant present a marked contrast, particularly in the case of fruit and vegetables. The issue of the product of the factory under a brand ensures care in the choice and grading of the raw materials. The product is processed so quickly after gathering that the freshness is preserved. Finally, the small amount of liquid used and the careful control of temperature and time of cooking result in a much more nourishing article of diet, and we are beginning to find that the sneers at the " living out of a can " type of housekeeping are not entirely justified.

Changing social conditions and customs also have an effect on the demand for canned goods. Woman's increasing participation in the fields of both work and pleasure have, with other factors, led to smaller families and consequently smaller houses. Increasing preference is displayed by girls for the office or the factory rather than for household work, and a wider social life is enjoyed by most people now-a-days. These have all gradually led to an increasing demand for quick and easily prepared meals—and the answer again lies in the can.

The motor car has made week-end travel, camping, and picnicking, more and more popular, and so further increased the call for easily transportable, hermetically sealed containers for food. Modern

12th September, 1939

civilisation is tending to assemble large urban populations into crowded industrial areas. The fight for markets, particularly overseas, brings an ever present threat of war. The development of aircraft, with their increasing numbers, speed, range, and striking power constitute a menace to all means of surface transport. A sudden raid might, in a few minutes, cripple and disorganise communication to such an extent that the evacuation, or the feeding from outside sources, of the population would be extremely difficult. The need arises, therefore, for some method of packing foodstuffs that will be at once easily portable, practically indestructible, and capable of preserving a variety food for indefinite periods. The answer to this problem lies, beyond all others, with the tinplate container.

Finally, from the point of view of the production engineer, the manufacture of this product presents a typical picture of mass production. Large bodies of totally unskilled labour are enabled to process and finally assemble huge quantities of interchangeable parts through the medium of tools supplied by a small body of highly skilled technical men.

It is true that the tolerances allowed are often comparatively large, nevertheless, there are occasions when, due to the nature of the material to be processed and the particular requirements of the job, very close limits have to be observed.

History.

The use of the terms " tin can " or " tin box " are, of course, misnomers, and are due either to ignorance or carelessness. The material used is tinplate and consists of mild steel with a coating of tin on each side amounting to a little over 1% by weight. Thus the strength, ductility, and toughness of the mild steel is made available, and its outstanding weakness—a great liability to corrosion—is safely overcome.

The art of applying a coating of tin to iron was known as early as 23 A.D., but comparatively little use was made of it until the middle of the sixteenth century. At that time we find quite a flourishing industry in Bohemia, whence it spread some years later to Saxony. In 1665 an Englishman by the name Andrew Yarranton, while travelling in Saxony gained a thorough insight into the method of tinplate manufacture, and he returned to England prepared to turn his knowledge to account. Apparently he was unpopular at Court, and the system then in vogue of granting manufacturing licenses to royal favourites prevented him from going further.

It was not until some sixty years later that Major John Hanbury successfully started the industry in South Wales. The Welsh tradesmen became very skilful, and handed their knowledge down from father to son until, as frequently happened in the story of British

crafts, the technique became almost hereditary. So strong grew the industry that for nearly a century South Wales enjoyed a virtual world monopoly of tinplate making. In 1891, however, the United States commenced manufacture, and by virtue of heavy tariffs built up the infant industry to such giant size that to-day it is the largest producer in the world.

Tinplate is now produced in many countries, but South Wales and U.S.A. provide by far the largest quota. It is of interest to note that plans are within measureable reach of achievement to establish the industry in Australia.

Manufacture.

The earliest method employed in tinplate making was to hammer the mild steel into sheets. About eight years after the introduction to England, however, the principle of rolling the sheets was discovered, and the much greater uniformity of gauge so achieved, opened up ever widening fields of employment for the new material.

The method of manufacture that was gradually evolved and which largely obtains even at the present day, is briefly as follows. Bessemer or open hearth steel is delivered in bars up to $\frac{7}{8}$ in. thick and 10 in. wide. They are sheared to the required length in accordance with the size of plate to be made, and after heating, are passed through the rolling mills. When sufficiently thin the sheet is doubled over and reheated. This process of doubling and rolling is repeated till the pack is eight sheets in thickness. The ends are sheared off and the pack passes to the opening department where the sheets are separated. After pickling in hot dilute sulphuric acid, to remove scale, and rinsing in water, the plates are annealed. They are now passed through a light rolling process to smooth the surface and, after further annealing, are pickled in a weaker solution of acid. A thorough rinsing in water follows to remove all traces of acid, and the plates are now ready for the application of a coating of tin.

The sheets are lifted from the water bath and enter the tinning machine through a flux of zinc chloride. This removes any water clinging to the surface and prevents oxidation. The sheets then travel through the bath containing molten tin, a coating of which adheres to the surface. The tinned plate continues its path through a vessel of hot palm oil in which it is carried through vertical rollers thus ensuring a smooth even coating of tin. Lastly, the plate is dried and cleaned in a mixture of bran, sawdust, and dried peat moss before receiving a final polish between sheepskin rollers.

The finished tinplate is carefully sorted. It is unfortunate that a very high proportion of plates are imperfect, and these are set aside and known as "wasters" to distinguish them from the "primes" or perfect plates. The term "waster" is perhaps a little harsh and "seconds" would be a better description, because

for all ordinary general purposes the plate is quite good. So high is the percentage of wasters, however, that with any special sizes, the buyer is compelled to take a proportion with every order. Of course, they are boxed separately, clearly marked, and invoiced at slightly less than primes.

Ebbw Vale.

Recent demands for sheet metal of uniform gauge, of great adaptability to die formation, and with a surface capable of taking the quick-drying colours and finish of modern coach body decoration, have led to a revolutionary change in manufacturing processes within the last ten years.

At that time a new technique was adopted in America and a so-called continuous process of hot and cold rolling was developed. This was so successful, that over the period mentioned, the output grew to the rather astonishing figure of 10,000,000 tons annually. For some time England lagged behind but in 1935 an effort was made to retrieve the situation. A mill was built and is now in full production and is turning out a product of excellent quality. The methods employed are such as to merit a brief description.

The whole plant is entirely self-contained. It manufactures its own steel from pig iron smelted on the spot in the company's blast furnaces. It prepares its own coke and the necessary gases for fuel and other purposes. Its raw material is drawn from the company's properties in other parts of the country, which include an iron ore field, five collieries, and various limestone quarries.

The steel is manufactured mainly in three Siemens-Martin furnaces and its composition is, of course, carefully dispensed to predetermined qualities. The ingots which weigh up to 10 tons are soaked in gas-fired furnaces before the rough rolling. The steel is handled automatically, and a few forward and reverse passes reduce it to a slab 6 in. thick and about 5 ft. 2 in. wide, the length depending, of course, on the amount of metal in the ingot. These slabs are hot sheared to suitable sizes for further rolling and placed into furnaces fitted with automatic temperature control for reheating.

At the necessary temperature the slabs are passed through a further rough rolling process. Five mills are used, and the strip of metal is progressively reduced in each mill. The first mill makes only a light pass to break the scale and high pressure water jets clean the surface. These jets operate on each of the rough mills and are automatically controlled by the passing of the strip. The most careful attention is given throughout to the elimination of scale and this care is well repaid by the quality of plate produced.

The strip is by now reduced to a thickness of about $\frac{1}{2}$ in. and is some 200 ft. long and ready for the hot finishing continuous rolling

operation. It passes over an air cooling table where the temperature is checked and reduced if necessary, to the required limit. Again five mills in line take care of the operation but the strip is now rolled in all five at once. As it becomes thinner and therefore longer, increasing roller speed is necessary and elaborate arrangements are made to graduate this accurately. These mills deliver coils of material about $^1/_{16}$ in. thick and 2,000 ft. long at a speed 1,850 ft. per minute. This stage marks the end of the hot finishing process and here the strips are passed through a series of pickling, rinsing, and drying tanks. The beginning of one coil is stitched to the end of the preceding one and a continuous feed is maintained. The strip is then oiled and rewound. At this point the paths diverge. Coils which are to be made into black sheets pass to the left to the huge cold rolling mill. Here, various rolling mills and rotary shears transform the coils to finished sheets of accurate gauge and size and beautiful surface finish.

For the purpose of this paper, however, our interest lies in the other direction. From the hot finishing mill the coils are carried by conveyors to the tinplate mills. Here is a similar line of five rolling mills taking the continuous strip, but this time the rolling is a cold process. The strip is here reduced to any dimension from about .078 in. to a minimum of .008 in. It varies in width from 12 to 36 in. and is delivered at a speed of 1,100 ft. per minute. Flying micrometers continuously indicate the thickness, and the sheets do not vary more than .0005 in. in thickness.

Many factors contribute to the attainment of this degree of accuracy. The rollers are comparatively small in diameter and have a carefully designed decreasing concavity of profile as the strip becomes thinner. Precision journals and heavy bearings play their part, and the temperature of the rollers is closely controlled. Accurate measurement by flying micrometer allows for the immediate detection of any variation. Finally, the composition, temperature, and tension of the material is vitally important. Any or all of these items have their effect on the finished product, and it becomes obvious that the design, manufacture, and control of them is a tremendous task. Coolant is liberally applied to all stages and, after recoiling, the metal is cleaned of grease and dirt electrolytically.

All annealing is done under close control and at no stage is self annealing allowed. The coils from the cleaners are packed on bases which are enclosed with a sealing cover, the whole being encased in a portable furnace, which can be used for several bases. The heating elements are enclosed tubes burning a mixture of gases and are responsive to accurate regulation of temperature. The heat is transferred to a special gas containing a proportion of carbon monoxide and carbon dioxide, and this in turn heats the coils. By this system no heat scale whatever is formed.

From the annealing furnace the strip passes through a tempering mill, which exerts a light pressure only, giving a work-hardened effect. The cutting up lines follow, where the coil is trimmed and sheared to tinplate sizes before tinning. In this process the sheets are pickled and then fed automatically through tin and palm oil baths, where the temperature of tin and oil are automatically controlled. The last two departments where the plate is examined, packed, and stored, are also kept automatically at uniform temperature to ensure the plate being kept in perfect condition.

The product of these mills is immeasurably superior to that of the older hot pack rolling method. The close control of material, composition, shape of rolls, and temperatures, result in sheets of a grain that will stand up to heavy press work and severe bending and folding, and a finish that is smooth, well tinned, and a splendid ground for decoration.

Tests.

I have conducted tests of the cold rolled plates, both on the bench and in actual production. The sheets are very square—an important point—particularly to the printer. They are accurate in their linear dimensions and live up to the makers' claim as regards uniformity of gauge. The metal appears to be somewhat softer than the hot pack tinplate and gives a good Ericsohn test. In a working test some 40,000 bodies were stamped and processed from each of three kinds of plate. In the result the total spoilage in all operations from the cold rolled plate was 1.004% as against 3.108% and 5.305% respectively of the hot pack lines. To further accentuate the difference and to test the manufacturers' claims only wasters were used of the strip mill plate and primes of each of the other lines.

In concluding the description may I be permitted to quote a few rather interesting facts to indicate the magnitude of the work ? The iron and steel industry has existed at Ebbw Vale, South Wales, for about a 150 years. Recently, however, until the opening of these mills, it was one of the " black spots " of unemployment.

The various mills cover an area two and a half miles long by three-quarters of a mile wide. The flow of production is in the form of a loop, raw material entering and the finished product returning past the one point and the whole plant is carefully designed to prevent any hold-up or jamming of the flow. The two blast furnaces can each handle 3,500 tons per week, and the three open hearth furnaces take a 75-ton load.

The 10-ton ingot, measuring about 2 ft. square is reduced to 6 in. slabs in eight passes in a mill driven by a 7,000 B.H.P. motor capable of delivering a peak load of 21,000 h.p. The time of reduction of a slab of two tons weight to a ribbon $^1/_{16}$ in. thick is roughly

three minutes, and it emerges from the last rolls at 20 m.p.h. In the cold rolling process coolant is supplied to the rolls at the rate of 500 gallons per minute.

The annual output is 500,000 tons of sheets. One could enlarge indefinitely upon the various points of interest but enough has been said, I think, to indicate the high technical skill and the tremendous courage which went to the building of this project at a time when trade was bad and the world was in a state of grave political upheaval.

Dies and Machines.

Before proceeding to a brief description of the various types of tinplate containers and the manufacturing methods employed, it would be well to consider some of the machines and tools which the canister maker employs.

Perhaps the most important machines are presses. These vary considerably in size but all have the basic principle of a reciprocating slide working in a plane vertical to a bed plate. They may be manual or power driven, and the motion is transmitted through cranks, cams, toggles, screws, or levers as the case may be. Each will take a fairly wide range of dies. Generally speaking, the type of die used is the combination, blanking, and forming die, although there are certain special jobs which are blanked first and formed to shape at later stages. The combination die takes two forms, but before describing them it is necessary to grasp two factors with which the tool makers has to contend. In the first place the low melting point of tin precludes any possibility of annealing at any stage in the operations on a stamping. Secondly, I should like you, in imagination, to take a sheet of paper and try to form it round the end of a cylinder or a cube. In the first case the paper would form into a series of more or less even corrugations round the side of the cylinder, and in the second it would fold nicely down the sides of the cube, but would corrugate deeply at each corner. Tinplate will act in the same way and the problem of the die maker is to form up the job without any unsightly grooves. In both types of die mentioned this is achieved by the judicious application of pressure, though by different methods.

The die used for deep drawn work in a double action press consists of three units. The plunger of hardened steel is made to the internal shape and dimensions of the required stamping. The top tool is of cast steel, not hardened, and is usually fastened to a cast iron bolster which is bolted to the ram. Internally, the cast steel is shaped to clear the plunger, and externally, it is the size and shape of the blank required to produce the stamping. The bottom face is given a high finish. The bottom die consists of three pieces. A hardened and tempered cutting steel is a sheer fit to the top die

and is fastened to a cast iron bolster which is bolted to the press bed. Resting on the bolster is a pressure ring of hardened steel, with a high degree of finish. Its internal dimensions are those of the plunger plus an allowance suitable for the thickness of tin being stamped. Its outer dimensions follow the internal portion of the cutting steel. In operation, the tin strip is held to gauges on the cutting steel and the press set in motion. The descending ram carrying the top die shears the blank and comes to rest pressing the blank on the pressure ring. At this stage the plunger descends forcing the blank through the pressure ring and drawing the tinplate against the pressure of the die faces.

In this type of die, it is possible to draw a round stamping to a depth equal to two-thirds the diameter in one operation. A different die consisting of two units is used for lighter stampings. The top die is frequently machined from a forging and is not hardened on completion. A stalk of the required diameter and about $2\frac{1}{2}$ in. long is machined true with the upper face and drilled down the centre and, in operation, is gripped in a suitable cavity in the ram of the press. The outside dimension of the top die is the blank size of the stamping. The inner shape and dimensions correspond with the outside of the proposed stamping. An expeller plate is made a sliding fit to this cavity and carries a stem which extends through the stalk and is held in position by a tension spring. Where embossing is required, it is cut into the expeller plate and the centre block in the bottom die. The latter consists of a cast iron bolster having provision for bolting to the bedplate of the press and machined true on its upper and lower faces.

A hardened steel centre block of the inner dimensions and shape of the stamping, is screwed to the bolster. The pressure ring is movable in this type of die and slides on the centre block. Its outer shape conforms to the blank and it has suitable checks to prevent it lifting above the level of the cutting steel. Round the centre block, holes are drilled through the bolster for the pressure pins. These vary in number and size with different stampings, but all pins in a die must be of equal length. A tempered cutting steel, finished to the blank size is securely screwed and dowelled to the bolster casting in the under side of which is a tapped hole. Into this hole a long stud is screwed after the die is set, which projects through the hole in the bedplate of the press. On this stud slide the upper and lower pressure plates, enclosing a rubber buffer and exerting pressure against the bottom ends of the pins on whose upper ends the pressure ring is carried.

In operation, the descending stroke of the press causes the die to shear out a blank from the strip and hold it between the face of the top die and the ring. Continuation of the stroke gradually forms the stamping round the centre block under continuous pres-

sure from the buffer. The upward stroke carries the completed stamping in the top die till a suitable knock out bar engages the top of the expeller rod and throws out the stamping.

The ironing out of the corrugations results in a considerable amount of wear on the dies. So regular is the effect that the drawing faces are worn into well defined grooves which in time make it necessary to reface the die. In the case of irregular dies the corners of the centre block will wear, though much more slowly than the faces. It must then be replaced. Double action dies on round work will give about 1,250,000 stampings before requiring repairs.

Irregular combination dies vary considerably in their need for repairs. Corners with a small radius or a deep draw will make for more frequent renovation. A body die with corners of large radius would give about 2,000,000 stampings and the complementary lid about 4,500,000. A small corner radius on the other hand would result in a reduction of about 500,000 stampings for the body and 750,000 for the lid.

Built up canisters of whatever shape have one point in common. An $\frac{1}{8}$ in. at each end of the blank is bent sharply over in opposite directions, and after the can is formed to shape these are interlocked and hammered down closely thus locking the body into the required shape. This side seam is locked in a machine resembling a press to which a horn of a suitable shape is fitted and which delivers a blow on the seam with a hammer bedded to the top surface of the horn.

The automatic body former which is suitable for long runs and which is really only a synchronized combination of several machines will be described a little later. The body former which is used on short runs of irregular shaped cans is a bench machine of either a power or manual type. Several spring loaded rollers extend the length of the machine and bear vertically on a forming block. This is of rather peculiar shape approximating roughly to the shape of body required. A steel strip is let into the block in such a manner that it will accommodate the hook on the body blank without play. The sides of the block are hollowed out to allow for the spring of the tinplate after forming. The blank is hooked into the slot and as the block revolves, the rollers, bearing on the blank, mould it into shape.

Round canisters are formed by rollers and the hook is put on after forming. Frequently, the hammer of the side seamer is constructed in such a way as to bend the hook at the first blow and flatten the seam at a second. These are perhaps the most important tools used but, of course, there are many others both of a universal and special purpose type and some of them will be briefly described a little later.

Boxes and Cans.

The various types of tinplate containers may be divided into three main groups, viz. the hermetically sealed, the air-tight, and the non-air-tight. The hermetically sealed can is the one most generally used for the packing of food. The closing end is permanently affixed, after filling, either by means of solder or of some sealing compound. It is seldom possible to decorate it directly, as the cooking process would alter all the colours. Labels are therefore affixed as a final operation.

The cylindrical can is most often used for fruit, jam, vegetables, soups, and milk. Beef is generally packed in the tapered rectangular tin. These are both built-up cans with top, body, and bottom as separate pieces. Fish, on the other hand, is generally packed in a can having a drawn body of oval or rectangular shape and a seamed or soldered lid.

The production of round cans usually follows a straight line. The blanks of the bodies are cut in rotary slitting machines and are required to be accurate to dimension and square. These are fed to the magazine of a body-forming machine from which they are drawn singly by a vacuum feed and reciprocating feed bars which carry them forward to the notching tools where an angular notch is cut out of each corner of the blank. The feed now carries the blank forward to the hooking tools which bend about $\frac{1}{8}$ in. of each end of the blank in opposite directions at an angle of 135°. After an application of flux to the hooks the blank is carried to the forming maundrel round which it is bent by the action of two semi-circular wings one of which acts slightly in advance of the other. The spring of the tinplate causes the hooks to engage and the maundrel expands at the same time holding them firmly in position for the blow of the seaming hammer which flattens the hooks and locks them into place. It should be noted that the side seaming is done at bottom of the maundrel. It is at this point that the reciprocating feed gives place to the continuous chain feed. A further fluxing of the seam takes place and the body is carried to the soldering iron. This consists of two bars of steel clamped face to face with small grooves cut into the internal faces. It is immersed in a bath of molten solder and projects about half above the surface. The solder is drawn through the grooves by capillary attraction, and the length of the bar is such as to allow for a thorough " sweating " of the seam. Revolving buffs wipe off surplus solder and air cooling jets cause it to set rapidly.

Owing to its cylindrical shape the body is adaptable to the use of gravity shutes, and by means of these and suitable elevators it is carried to the flanging machine. Here dies are forced into each end of the body turning up $\frac{1}{8}$ in. of flange all round the tin. It is at this point that we notice the necessity for the notches. The side

seam now contains four thicknesses of plate and this would interfere with the flanging. The notch, however, has removed two thicknesses, and where the flange is formed there is only a lap joint to contend with. In the following seaming operation, too, the notch, by removing the surplus metal allows a closer application of the seaming wheel and consequently less chance of a leak. At this point a branch line converges on the main production line. Automatic presses blank and form the circular bottoms and discharge into rotary machines which curl the flanges of the bottom slightly. This curl serves a dual purpose. It prevents the stampings from " nesting " and so jamming the magazine feed of the double seamer and also helps the seaming wheels in their curling operation. A further machine applies a coating of sealing solution—usually rubber—into the channel so formed, and the solutioned ends after drying are fed to magazines of the double seamers. Here they are assembled with the body and spun on a head. Two grooved wheels are gradually advanced to engage the flange on the bottom stamping and curl it tightly down on to the body of the can.

In view of the vital importance of the air-tight quality of the can a final test is applied. A multi-head machine picks up the cans automatically—seals the open end with a rubber pad—and injects air under pressure. Suitable recording instruments ensure the rejection of leaky tins.

In packing certain products, notably fruit, peas, and meat, it is necessary to lacquer the plate. These goods have a chemical reaction to the tin on the surface, which would result in an unattractive discolouration of the contents of the can. The plate after cleaning, therefore, is passed through soft rollers revolving in the lacquer and a coating is applied which is dried on the tinplate by stoving for thirty minutes at 200°C. Grooves are cut at suitable positions in the rollers so that lacquer will not be applied where it will later be necessary to solder the can. The ovens are fired by gas or fuel oil and are thermostatically controlled. A plant such as described is capable of producing tins at the rate of 330 per minute. The cans are sent to the packer accompanied by a similar number of loose tops curled and solutioned ready for double seaming to the can after filling. A precisely similar machine is used to that described for seaming the bottoms.

It is still the practice in some places to puncture a small hole in the top of the can before cooking. This is particularly useful in the case of certain types of meat which give off hydrogen sulphide during retorting—a chemical which would probably stain the contents of the can very badly. The gas is driven off through this hole, however, which is soldered while the can is still hot and, on cooling, a partial vacuum results.

Whilst on the subject of meat canning it may be of interest to

members to hear the adventures of a 4 lb. tin of veal. It was packed in 1824 and bears on its label the words "Cut round the top with a hammer and chisel." The reason for this instruction lies in the fact that the world's first cannery was opened in London in 1811, and the tin opener had yet to be invented. In 1824 with some 25,000 of its brothers it journed on the *Hecla* with Parry's third Arctic expedition. It returned unopened and, two years later, was taken on the fourth expedition. Still unopened, on return it drifted with other mementos to the Royal United Service Museum in Whitehall, where it remained in a case subject to day-to-day changes of temperature for 114 years. It was discovered there by the Tin Research Council and permission obtained to open it. Professors of bacteriology, biochemistry, and physiology conducted tests and, in the words of their report "The meat was in a perfect condition." In taste, colour, and odour it had not deteriorated, and vitamin tests compared favourably with fresh killed veal. The wrought iron plate composing the can was .0185 in. thick with a coating of .0005 in. of tin. May I repeat, the technique of canning was only twelve years old and for forty years after nothing was known of bacteria, moulds, or fungi which might attack foodstuffs. This can was not specially packed but just one of the batch—a vivid testimoney to the wholesome nature of canned foodstuffs.

It has already been admitted in the introductory paragraphs of this paper that, generally speaking, the tolerances of canister making are large from an engineer's standpoint. An example shows what can be achieved, however, should the necessity arise. Ten double action presses were producing a tin at the rate of 100,000 daily which entailed the provision of 10 further body dies for replacement. The tins were trimmed and swadged and delivered to stock where they remained for varying periods up to eight weeks. The action of blanking and drawing the tagger top, however, necessarily exposes a raw edge of mild steel which in forty-eight hours becomes tarnished to such an extent as to interfere somewhat with the soldering operation. To achieve the necessary output four and sometimes five dies were in daily operation with, again, a similar number for wear replacement. The problem was to supply taggers daily to fit any body in such a way that girl operators could assemble them easily without distortion, and which would yet be tight enough to hold against the pressure generated in the tin by the heat of the soldering machine. A centre block tolerance in the tagger die of .0005 in. was all that was allowable.

The majority of hermetically sealed tins when once opened are of no further use as containers. There is one type, however, for your consideration, which displays points of interest. The lid is formed with three indentations in its circumference and a formed channel is filled with a rubber solution. The body is curled at the

top to form a seat for the rubber seal, and has two beads formed on the side. The lower one is merely a fulcrum for leverage in removing the lid. The upper bead engages with the indentation on the lid. After filling, the lid and body are assembled and the tin is exhausted in a vacuum chamber. When the vacuum is broken and part of the contents removed, the lid may be re-placed repeatedly and the engagement of the bead and indentation will reseal the rubber band on the top of the tin and provide an air-tight container.

The vast resources for growing fruit, vegetables, and meat, and the teeming millions of fish around our shores offer a vast field for the canning industry in Australia—a field that is only scratched on the surface as yet. I believe that the time if not far distant when the appalling wastage of our glut seasons will be turned to profitable account, and the wonderful sunshine of our country will be literally preserved in the millions of cans of natural produce that will be exported overseas.

Before passing to a description of air-tight and non-air-tight containers both of which are often decorated, it would be well to learn something of the printing process employed. This is known as lithographic offset printing.

The rotary printing machine has three synchronized cylinders. Round one of them a flexible zinc plate is fixed, the grained surface of which carries an impression of the design to be printed. Suitable arrangements for feeding both ink and water to the plate are included. The second cylinder bears a tightly stretched rubber blanket which, as it revolves against the zinc plate, receives an impression of ink. The third cylinder has a gripper attachment for holding the sheet to be printed. The latter must be pliable enough to conform to the surface of the cylinder. As it revolves, it comes in contact with the freshly-inked rubber blanket and takes the impression.

The resilience of the blanket allows of sufficient pressure being applied to obtain a clear, sharp impression—a matter of impossibility if the tinplate to be printed were brought into direct contact with the zinc or aluminium machine plate from which the design is printed. Each colour is printed separately and it should be noticed that tinplate is always printed in the flat sheet and made up afterwards.

In addition to the lithographer's usual difficulties of getting the correct colour values and building up, colour by colour, a composite design in perfect register, tinplate printing offers its own special problems. The non-absorbent nature of tinplate makes it necessary to stove each colour before the succeeding one can be applied. Great care is necessary in the stoving or the colour will be completely altered and even in some cases disappear, and the completed job will be quite different from the original. The temperature of the plate must be watched as it is fed to the printing machine so that the expansion due to the stoving heat will not affect the register

of the colours. It must be remembered that the tinplate has frequently to be drawn severely in the making-up processes, and the printed design must stretch considerably without cracking or flaking. Careful stoving plays an important part here also.

Owing to the possibility of stretch in the blanket care must also be taken that the printed job does not vary in size from the machine plate from which it is being printed, as this would make it impossible to obtain a perfect register of the design in the formed-up stamping.

A short description of the procedure adopted in the decoration of a box may be of interest. The first stage is the preparation by the litho artist of a complete sketch in colour drawn to the correct size and containing every detail that it is required should be printed. The colours must be kept down to a minimum to achieve the desired result because every additional colour means a further run through the machine. Certain effects can be obtained by super-imposing colours but the finer shadings are obtained by stippling—that is the printing of innumerable tiny dots of one colour interspersed with dots of another. At a little distance the effect obtained is that of a blending of the two colours used. It is often necessary to distort portions of the sketch so that when drawn in the die it will assume the required appearance.

After completing the sketch it must be analysed into its component colours. A transparent mica sheet called a key is placed over the sketch and an outline of each colour is engraved on it. At suitable places small crosses are made to act as register marks when setting up the printing machine. This sheet is dusted with jewellers' rouge and an impression is taken from it on to a zinc plate for each colour in the finished design. The artist fills in each plate so made with litho-ink according to the amount of colour to be printed. The surfaces of these plates, called originals, and that of the machine plates are grained with an infinite number of tiny cells whose purpose it is to hold water. The original is rolled up with an inky roller and a black impression of an original is taken on tinplate varnished and stoved, and tests to ensure its accuracy.

A layout is made to discover the most economic size of tinplate for the job and the step and repeat machine is set up accordingly. This is really a hand operated printing machine and it accurately repeats individual impressions from the original on to a rubber blanket and thence to the machine plate at the pre-determined positions. The machine plate is damped and rolled up with ink. After careful examination to see that all impressions are clear and sharp it is etched outside the design with gum arabic to a depth of .001 in. A black impression of the plate is taken and tested with straight edge and dividers, to ensure that the impressions are equidistant and in straight lines. After thorough cleansing and drying it is covered with a coat of soluble gum to preserve it and

sent to the machine room. Each colour in the design follows the same procedure.

The camera, of recent years, has played an increasingly important part in lithography. It has been freely used to save actual drawing and for accurate enlargement and reduction. The technique has so improved that it is now possible to reproduce a job in colour through all stages, including the machine plates, entirely photographically.

Although the method just described is still the most generally used, modern plants have installed and use photo-litho equipment almost entirely. There are, as you know, three primary colours—red, yellow, and blue—and from combinations of these almost all other colour hues are formed. The sketch or colour photograph which it is required to reproduce is attached to a copy board under a strong arc light and the camera is focussed. Without moving the camera four photographs are taken on panchromatic dry plates through colour filters, which represent respectively the red, yellow, blue, and black in the original. This, of course, results in negatives of the red, yellow, blue, and black colours in the original sketch.

The camera used in this work is 37 ft. long. The object to be photographed is fastened to a back-piece which, together with the camera, is spring suspended from a strong iron frame. Building sway and vibration thus move camera and object in unison and the result is a sharp, clear negative. The lighting is provided by a special 3,000 watt mercury water cooled lamp with an actinic value of $^1/_5$—that of the sun.

Where the reflected light from the object or copy has fallen strongly upon the photographic emulsion, a latent image is formed. This " latent image " is uncertain as regards actual composition, but is supposed to consist of small particles of metallic silver, which act as a nucleus about which the developing operation proceeds. Therefore, the part of the emulsion which has been affected by light reflected from the object, assumes a black appearance on development, and these parts are rendered insoluble in the thiosulphate or hypo fixing solution which dissolves the unexposed silver halide emulsion. The final image consists of grains of metallic silver suspended in the gelatine emulsion. The negatives are carefully examined, and where the judgment of the artist dictates in the light of his experience of colour blending and superimposition, the negative is " corrected." A good deal of manual skill and a profound sense of colour value is required for this process, but it is now possible to compare mechanically, the strengths of tone in drawing and negative.

The colour value meter is used in conjunction with a chart of colour combinations on which, for purposes of measurement and comparison, each colour is assumed to have ten strengths. There

are 15,000 different blendings of red, yellow, blue, and black in this chart so that it is possible to match any conceivable shade. The various colours in the drawing of the job to be printed are compared with this chart and when a match has been obtained it is possible to read off the strengths of the component primary colours.

The meter itself consists of a vertical frame into which the negative can be locked. Above the frame are ten apertures about 1 in. square filled with glass ground to varying degrees of opaqueness corresponding to the ten strengths of colour previously mentioned. Behind the negative a rapidly adjustable table carries a strong light which is focussed to a narrow beam. Axially in line, with the beam, but in front of the negative is a photo-electric cell connected to an ampmeter, the whole being carried on a projection from the table carrying the lamp.

A reading is taken first with the beam playing through the apertures corresponding to the colour strength desired. The light is now shown through the negative and a reading taken which should correspond exactly. If necessary, adjustments of colour value are made by adding to or lightening the tone of the negative. When the whole of the negative has been treated in this manner a very acurate colour strength is obtained.

When the positives are made from these completed negatives a half tone screen is interposed. This screen consists of two sheets of glass accurately engraved with diagonal lines and placed face to face in such a manner as to form small squares. These vary in size according to the job and may run as fine as 200 to the inch. The object is to break up the photo into tiny square sections which will give the same effect as the stippling previously described.

The positive is photographed by projection enlargements direct on to the machine plate. Micrometric adjustment of the positive is possible both vertically and horizontally resulting in a machine plate accurate to .001 in. The emulsion on the machine plate is of a chemical composition of such nature that the portion exposed to light becomes desensitized and the image of the design may be washed away. The plate is etched to about .001 in. deep and is rolled up with litho ink. The desensitized emulsion is then dissolved and the plate cleaned, dried, and gummed up for the machine room. It is possible by the photo-litho process to save a tremendous amount of machine-room time. It was not uncommon for ten or twelve colours to appear in a high class job such as a showcard. This meant a similar number of runs through the printing machine. These can now be made in four printings on paper and a finer, softer result obtained.

In respect to the printing of a similar job on tinplate more runs would be required. In the first place it would be necessary to print

two whites to kill the metallic sheen of the tinplate and form a base on which to build the design. Depending on the nature of the job, it might also be necessary to print an additional tint to reproduce the colours with actual fidelity.

The art of lithographic printing is dependant on the fact of the mutual aversion of grease and water. Provision is made in the printing machine for a supply of water and ink to the machine plate. The water adheres to the tiny cells in the grained surface but does not touch the design which is of a greasy nature. The printing ink, on the other hand, clings to the design but refuses to adhere to the damp portion of the plate. The wet ink is printed on to the blanket and this in turn records an impression on the tinplate.

The printing machine is synchronised with a conveyor passing through an oil or gas-heated thermostatically controlled oven where the tin plates are heated and dried and finally cooled again before delivery. As a final operation a coat of varnish is applied and baked. This gives a protection to the colour in the forming operations beside adding a finished appearance to the job. It is better, if possible, to allow the job to stand for a few days before working.

Air-tight Container.

The air-tight container is quite unsuitable for the preservation of foodstuffs, but covers a large field where the contents need to be available in small quantities, yet are of such a nature that under exposure to air they would deteriorate. They are useful for packing solids, or liquids of medium or heavy viscosity. They are usually, though not necessarily, of cylindrical shape, and in any case are generally closed with either a push-in cap of tight fit or a screw top. They are made on the same types of machine as the hermetically sealed can, but at a lower rate of production. They can, however, be highly decorated except where soldering has to be done when a strip of plain tin is left unprinted. Paint and oil tins are typical examples of this class of work.

Non-air-tight Box.

The non-air-tight box furnishes a method of packing goods in an easily accessible manner, in standard quantities for retail distribution and at the same time, preserving them from damage or deterioration. Although unsuitable for liquids it is extremely useful for pastes and solids. It can be made in a large variety of shapes and styles and is on occasion highly decorated, the comparative indestructability of the print forming a permanent advertisement.

Owing to the non-hygroscopic nature of tinplate even the non air-tight tinplate box will preserve its contents better than most other packs.

Two examples have been chosen for your consideration which, whilst possessing many points in common, have been produced with different objectives in mind. The first example is that of a caddy. Its structure is such that it will keep its contents in good condition but it is unnecessarily elaborate for that function alone. Its main objective is sales appeal. The pleasing shape and beautifully printed body give the effect of a china vase and the feminine mind particularly, will visualise all kinds of useful purposes that it will serve after the lollies it contains have become only a memory. The packer's name does not appear anywhere on it and as a consequence it will be preserved and even given prominence in the home and form a continual reminder of its original contents. This is a subtle, but very efficient form of advertisement. This caddy is printed in ten colours. It has ten separate pieces each of which are submitted to various operations before assembly and, in the aggregate, there are 41 operations on each completed caddy.

The handle of the lid is made of two pieces which are blanked, formed, assembled, and clenched leaving tabs outstanding to clench through the top of the lid. The latter is stamped in two pieces and after the handle has been fastened to the top piece, they are assembled with a square of cardboard between and the upper portion of the lid is clamped to the lower in a curling die. The four sides of the body are blanked in the flat. They are folded at the top to form a safe edge and hooked to take the bottom at a later stage. The blanks are formed to shape and the hooks formed on the sides. These are assembled and locked firstly and in pairs and then in complete bodies. The bottom is blanked and turned up at the edges. It is sprung into the body and then clenched down. The elaborate tooling requires a fair amount of lubricant to preserve the print so finally the caddies are carefully wiped and examined before packing. It is perhaps of interest to note that with a caddy of this description, the dies would cost about £500 to produce.

The second example before you is a hinged lid box. Though attractively printed and forming a good advertising medium it is designed principally for utility. It is strong and shaped to fit the pocket easily with no outstanding corners. It will preserve its contents from atmospheric changes and damage, and can be opened and shut indefinitely without impairing that efficiency in any way. The box consists of a lid and body each of which is submitted to several processes before and after assembly, amounting to thirteen in all. The body is formed, trimmed, the hinges pierced and formed, and the projections on the front embossed. The lid is formed, curled, the hinge slots pierced, and the thumb bit embossed. The latter serves as a method of locking the lid in its closed position.

Lids and bodies are now assembled and closed. Thorough clean-

ing is necessary to remove lubricant and all boxes are gauged to ensure that they will pass through the automatic wrapping or banding machine after they are filled by the packer. Careful final inspection follows before packing and delivery. The box in question offers a good example of mass production methods, the quantities involved being large enough to warrant special arrangement of plant and tools to form a complete unit.

Three No. 3 presses with combination dies such as those previously described blank and form the bodies. Ejection from the press is rigidly controlled so that all bodies are discharged uniformly on to the conveyor. This is necessary both from the point of view of the shape of the body and also occasionally the printing, which must be assembled in correct relation to the lid.

The conveyor carries this accumulation of bodies to the three trimmers where the edge of the stamping is trued up. Coupled in tandem, so that the body is control-fed to them, are the tools for piercing and forming the hinge pieces and embossing the front of the body. From here they are discharged to a central belt and conveyed to the assembling and closing machine. The lids are stamped in a second line of lighter presses and conveyed to the curling machines where the flanged edge is turned up in a die.

From this operation belts convey them to the curlers where the curl is completed. This curl strengthens the lid, improves the appearance and safety of the box and acts as a hinge pin. Tandem coupled to the curling operation are the tools for piercing the slots immediately above the curl and also the tools for embossing the thumb-bit. The lids are discharged to a belt which feeds the automatic assembling machine where the lid is hooked to the body and the hinge pieces closed. A final belt carries the boxes to the packer. On their way they are wiped and tested and returned to the belt.

The unit is not easily interchangeable for size but two different prints may be handled at the one time in emergency. The staff required is 21 girls and three youths, all unskilled labourers. The floor space required is about 1,200 sq. ft. In a Sydney factory where five of these plants are installed the output for the month is an average of 7,000,000 complete and perfect boxes, and this is capable of at least 15% expansion if orders are available. Considering the number of the staff and the floor space occupied this is a truly surprising figure.

Discussion

MR. E. C. PARKINSON (Section President): Personally, after hearing this talk, I feel I have far more respect for the humble tin container than I may have had for its contents.

MR. OLIVER: Have you had any experience with the use of hard chrome plating on drawing dies?

MR. INGLEDEW: No. So far, I have not experimented with the chrome plating of dies. I think it is possible that in some form of die it would be suitable.

MR. OLIVER: Would the circular form be suitable for chrome plating?

MR. INGLEDEW: I think, possibly, it would.

MR. LANGMEAD: Are there any lubricants used on the dies?

MR. INGLEDEW: Yes. Most stamping operations require lubrication. With plain stamping a special self-drying mixture is used which does not require much cleaning afterwards. It is in the nature of the coolant used on machine tools. With printed tinplate a light oil is used. Shallow stampings can be done with very little lubrication.

MR. STEER: In the lay-out you showed on the board, I should imagine that the machines would be fairly complicated. What steps would you take in respect to breakdowns?

MR. INGLEDEW: The unit is not running at full production to get the figure that I gave you. The early operations are slightly faster than the later ones and as a consequence there is a slight accumulation of stampings. In the event of a stoppage on one machine these may be fed to the duplicate machines and so keep up the general average.

A VISITOR: With regard to automatic sealing, is there any distinct advantage in using red rubber as compared with white rubber?

MR. INGLEDEW: We use white rubber in some cases, but it is applied in rather a different manner to the one I described. In the type of tin on exhibition, red rubber is used universally

A VISITOR: The composition of red and white rubber is different. White rubber is distinctly harder and is not affected by heat. Does that affect its use for your purposes?

MR. INGLEDEW: For that particular type of job, no heat is applied, except in the original drying of the solution. It is sprayed in under compressed air, and then placed in an oven, which dries it in about an hour and a half. At the end of that time it is not so much dried as congealed. It is necessary for the stamping to stand for a period of about two days before it will actually stand

up to the exhaustion process. On this method of sealing a soft rubber is preferable.

MR. LANGMEAD: How many rejects do you get?

MR. INGLEDEW: We get a few faults, but 99½% are air-tight tins. If you strike a batch of tinplate which is not up to standard, faults will occur. During stamping and the consequent stretching which occurs, the metal becomes slightly hardened, and in the curling process which is applied to the top of the tin, there is a tendency in some classes of plate to get minute fractures, but generally speaking they are pretty efficient

MR. MCPHEE: I have no hesitation in saying that the machine described by Mr. Ingledew is more in the nature of a mass production plant than anything I have seen before in Australia. Most of our plants are not really so in the fullest sense of the term. It is an excellent example and I would advise you to take the opportunity of seeing it in operation. Another point is the bringing together of manufacture and art. Not many years ago they were something entirely different. Now we have arrived at the stage when great numbers of products have art behind them, and the manufacture of cans is an excellent example of the combination of the artist and the manufacturer.

Mr. Ingledew has given us a vivid picture of the evolution of the tin can from the raw material of iron, coal, and tin to the finished article, and I think, in future, we shall all have more respect for the tin can.

ACCEPTANCE TEST CHARTS FOR MACHINE TOOLS

PART I

THE Standing Joint Research Committee of the Institution of Mechanical Engineers and the Institution of Production Engineers announce the publication, jointly by both Institutions, of a series of ACCEPTANCE TEST CHARTS FOR MACHINE TOOLS (Part I, pp. 15, six charts, 5s. 6d. post free. Single charts 6d. each).

Adoption of Charts Recommended.

In view of the urgent need for the abundant supply of machine tools of the highest possible accuracy, the Joint Research Committee consider that the conditions created by the state of war call for the immediate publication and use of the charts. *They therefore recommend the adoption of the charts, wherever possible, by those members of both Institutions who are responsible for the use of machine tools.*

Grounds for the Recommendation.

The belief that the national interest will be served by this course is based mainly on the following grounds :

(1) That the use of the charts need not be a cause of any delay in the production of machine tools, but rather will greatly benefit the manufacturing side of engineering in the present emergency.

(2) That the large number of firms now embarking for the first time on the manufacture of machine tools will be materially assisted in the difficult task by having as a guide authoritative acceptance tests for first grade machines which have been endorsed on behalf of users, even when such tests are not specified when machines are being ordered.

(3) That, since many well-established British machine tool makers are already working to limits finer than most of those specified in the charts, the adoption of the acceptance tests need present no difficulty to them, while many newer firms, in the absence of the guidance afforded by the charts, would have to rely on methods which would not give the user so satisfactory a product.

Types of Machine Tools Dealt With.

The publication includes acceptance test charts for centre lathes up to 16 in. swing, milling machines (knee type, horizontal and universal), vertical milling machines, horizontal slab or vertical milling machines, plain and universal grinding machines, and radial drilling machines, all machines being of first grade.

It will be noted that only a few of the leading types of machines are covered, but work on the preparation of charts for other types of machines is in progress.

Not for Use of Makers Except as Standard of Reference.

An account of the origin of these acceptance charts is given, and it is pointed out that they are not intended for the use of the maker of machine tools except as a guide and a standard for reference.

The tests themselves embody the basic requirements of the two main systems, namely, " geometric " and " practical " tests.

The charts are divided into three sections under the headings of levelling, alignments, and practical tests. Instructions are given for the application of the tests, and the instruments and tools used for measurement are dealt with.

Acceptance Test Charts for Machine Tools can be obtained from the Institution, the price, as announced above, being 5s. 6d. post free, while copies of single charts can be obtained at the price of 6d. each.